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POWER REQUIREMENTS OF THE 200 BEV FACILITY

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In response to your inquiry of September 16, 1966, the electric power needs of the 200 BeV accelerator facility have been extensively reviewed; the results are given in the answers below. Using the scope of activity presented in the Design Study Report, a schedule of operation for the accelerator and for the experimental equipment has been developed. The schedule was modeled after the programs at BNL, CERN, and LRL with modifications appropriate to the new 200 BeV facility. Total power requirements presented here were derived from this model of the project. Any such projections of the detailed activities of a research project for a decade into the future must be subject to considerable uncertainty; an allowance of ± 30% in the needs of the laboratory would not be unreasonable.

Answers to the questions follow.

1. Power demands and annual energy requirements are given in Table I.

2. Example monthly power demands and energy consumptions after completion of construction are given in Table II. Fluctuations in energy figures result from an assumed shutdown schedule, the details of which are actually quite unpredictable at this time.

   Power factor would be approximately 80% over this period.

3. <u>50 MVA in 1-to-10 sec, 2-to-4 per day:</u>

   The average value of the pulsed (on and off every 2.6 second cycle of the accelerator) load is 50 MVA. This is supplied by generators

Table I.

Electrical Demand and Energy

Year	1/2 hour Demand-MVA	kWh x 10^6 per year	Load Factor 8760 hrs/yr	Comments
0-1	0.7	0.35	5%	Title I Clear site Temp. support bldgs.
2	1.5	4.2	35%	69 kV AC power
3	5.5	9.0	20%	Main substation
4	13.5	21.5	18%	Linac, injector 13.8 kV AC distribution
5	30.0	41.0	16%	Main ring comp- lete Superperiod "A"
6	56.0	120.0	25%	Linac turn-on Injector turn-on "H" EPB
7	80.0	160.0	23%	"I" EPB Main ring turn-on "J" EPB Construction complete
8	100.0	450.0	50%	Operations phase
9	120.0	600.0	57%	INITIAL LOT OF COOLING TO HERE ?
10	140.0	730.0	60%	
11	150.0	800.0	61%	
12	155.0	850.0	59%	
13	162.0	870.0	60%	

Operation Schedule

Holidays	15 days
Maintenance	57 days
Outage	18 days

Demand for Non-operation periods

Minimum	20 MVA

Table II.

Monthly Energy Consumption - Demand

Year / Month	1st Year kWh x 10^6	1st Year MW	3rd Year kWh x 10^6	3rd Year MW	5th Year kWh x 10^6	5th Year MW
January	33	80	66	125	74	150
February	33	83	48	126	60	151
March	40	88	67	127	75	152
April	12	89	68	129	75	152
May	40	91	69	130	47	153
June	41	93	41	132	75	154
July	42	95	70	133	76	155
August	35	97	70	135	76	156
September	43	99	71	136	76	156
October	44	101	71	138	58	157
November	32	102	55	139	77	157
December	45	104	72	141	77	158
	450		768		846	

which store substantial quantities of energy. The generators are driven by motors with controlled power input (wound rotor motors for example). The pulsed loads may be terminated abruptly during either test or operation by the operators or safety interlocks. The motor input power will then be quickly reduced to no-load losses in a time which is simply the quotient of the change in mechanical stored energy and the average motor input. The motor input power will be programmed to minimize power rate variations but if the interruption occurs near the end of a pulse instead of near the middle, the cut-off time will be only one second. Resumption of pulsing will re-establish the power load in ten seconds.

50 MVA in 0.1 sec, 0-to-1 per day:
The largest single circuit will be 50 MVA. An overload or safety interlock would trip the breaker in 100 milliseconds.

120 MVA in 10 minutes, 1 per day:
The 120 MVA load change represents the pulsed load plus the other normal loads associated with the operation of the accelerator and the experimental areas. Any shutdown for machine maintenance scheduled or otherwise will require this equipment to turn off. The pulsed load will terminate in ten seconds, the rest of the load can be scheduled to go off over an interval of a few minutes.

4. 20 MVA in 1-to-10 sec, maximum 20 per hour;
20 MVA in 0.1 sec, 1-to-3 per day:
The description of the loads is the same as for Question No. 3, but occurrence frequency of the "stop pulsing" and "resume pulsing" commands expected is much higher than during normal operations. It is not meant that the load changes will occur at 20 per hour for all hours of testing. The rate will frequently

be much smaller, however it is not possible to predict when and for how long the need for such operation will exist.

5. Normal load variations are the same as in answer to Question No. 3.

6. Setting a proper limit here is more difficult than tabulating loads and calculating regulation. It involves judgment as to what really will be detrimental to the accelerator operation. It is anticipated that much equipment will be provided with built-in regulators because the tolerance in its output is much smaller than could be realized by a well-controlled power system. Examples are beam bending magnet power rectifiers which are regularly designed for 0.01% control of current. Of course, the power supply voltage perturbation adds to the magnet resistance variation to increase the range, and hence size, of the regulator as well as the required loop gain of the amplifier. Loop gain is cheap in terms of electronic components but the gain-bandwidth product of a device is finite so that increase gain usually means a sacrifice in the frequency response of the device.

There will be other ranges of required voltage stability. For example, the quadrupoles of the injector linac can probably tolerate as much as 1%. Much of experimenter electronics, counting equipment, experimental setups in the laboratories, closed circuit TV's and computers are also in this range. Also, the other customers of the utility who are connected near the point of load will have complaints at numbers a bit higher than 1%. For example, a 2% change produces a noticeable size change on a television screen.

The laboratory power system is made of several 50 MVA transformers. The secondaries will be separated so that the various kinds of loads can be isolated. To provide as much flexibility as possible, the ultimate limitation of the voltage stability should be the regulation of these transformers and not the power grid feeding the transformers. The transformers will have a short circuit MVA of 600 to 1000 MVA, so the grid should have at least 4000 to 6000 MVA, which permits a 1% voltage swing on the grid.

7. In calculating the voltage variation produced by a current change ΔI,

$$\overline{\Delta V} = \overline{\Delta I}\,\overline{Z} = |\Delta I|\,(R\cos\theta + X_L\sin\theta) + I_m,$$

where θ is the power factor angle,
the imaginary part is so small when added in quadrature that it can be neglected. Thus, the relative voltage change can be expressed in terms of the power change as

$$\frac{\Delta V}{V} = \frac{|\overline{\Delta I}\,\overline{Z}|\,V}{V^2} = \frac{\Delta P}{kVA_{\text{short circuit}}}$$

The short circuit information normally is determined to allow proper application of the circuit breaker to be installed. It is, therefore, calculated with all generating equipment connected and operating. However, less than 100% of the generators are on the line much of the time.

In contrast to locations where the source impedance is determined by the line or transformer, the accelerator will be connected to a very low impedance point of the system. In this case, the impedance will be determined by the actual number of generators connected. The quoted MVA should then be reduced by a factor to represent actual conditions when calculating the regulation.

An additional factor not yet evaluated arises from the fact that for load changes occurring in about one second the transient impedance rather than sub-transient reactance should be used; this will increase the source impedance and the voltage regulation by as much as a factor of two. On the other hand, the time is too short for most generator voltage regulators to be effective.

To calculate the short circuit kVA, a factor of 0.7 has been used for the above adjustment. Also assume

$$\frac{\Delta V}{V} = 0.01 \qquad \frac{R}{X_L} = 0.1$$

$$PF = \cos\theta = 0.8$$
$$\sin\theta = 0.6$$

$$\text{kVA} = \frac{\Delta P}{0.7}\ \frac{V}{\Delta V}\ \left(\frac{R}{X_L}\cos\theta + \sin\theta\right)$$
$$= \frac{(50 \times 10^6)\ (0.68)}{(0.7)\ \ (0.01)} = 4860 \times 10^3 \text{ kVA}.$$

8. There appears to be little in the accelerator design, other than electric clocks, which is sensitive to frequency. Of course, the stored energy in the motor-generator system will be affected, but this is not objectionable unless the excursion is large. A frequency tolerance of 1% appears to be adequate. The normal frequency control of power networks is better than this.

9.(a) Changes in technology could alter the types of research equipment in use. An example would be the advent of large-scale use of superconductors in magnets. In the estimates made above, only the large bubble chamber was assumed to have superconducting magnet coils. About three years after the end of construction, 35 MW of average load will be rectifier-powered d.c. magnets. Extensive use of superconducting coils would reduce this load to about 5 MW of motor load for the cryogenic systems. These cryogenic systems would operate with fewer interruptions than the corresponding conventional magnets.

(b) In the program of a research facility, unexpected projects may arise at any time. To allow experimental development to proceed without delay the laboratory should be free to introduce new equipment and operating procedures. For example, it should be possible to test new pulsed devices in the development laboratories without interference to other equipment of the project and without the need of a flywheel-buffered power source. Also, it would be disadvantageous if the use of new or added devices had to await the expansion of the power system. Thus, the flexibility of the power network to supply changing loads is a positive asset to the laboratory.

(c) The expected rate of power interruptions would determine the amount of emergency power facilities required on the site. A modest amount, about 5 MW, of emergency power can allow operation to resume within one hour after a brief interruption that lasts less than an hour. On the other hand, an interruption of a few hours to systems maintaining high vacuum or low temperature may require many additional hours to recover operating conditions.